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RESEARCH MEMORANDUM

INVESTIGATION OF A CERMET GAS-TURBINE-BLADE MATERIAL OF TITANIUM CARBIDE INFILTRATED WITH HASTALLOY C

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

A Hastalloy C infiltrated titanium carbide cermet was investigated as a potential material for gas-turbine blades. Small gas-turbine blades made of this cermet were run with HS-21 alloy blades, which were used as a control sample. Two turbine speeds were used and were selected to produce average failure-zone centrifugal stresses of 15,300 and 19,800 psi in the HS-21 alloy blades. Turbine tests were run at a turbine-blade temperature of approximately 1500° F; stress-rupture tests were conducted at 1600° and 1800° F.

The cermet blades survived as long as approximately $312\frac{1}{2}$ hours of operation at 1500° F with an average midspan centrifugal stress of 11,500 psi. All cermet blade failures could be attributed to flaws in the material or to external causes, such as impact or excessive vibration.

The cermet and alloy control blades sustained damage from external causes, which prevented a reliable comparison of operating lives.

Root failures have been generally encountered in earlier studies of cold-pressed and sintered cermet blades of similar shape. The blade failures encountered in this investigation were generally in the airfoil. Blades of the present composition thus seem to be less sensitive to notch effects.

INTRODUCTION

Cermets are being investigated for gas-turbine-blade materials because of their promising high-temperature strength and low strategic-metal content. Application of cermets, however, has been hampered by their lack of resistance to impact. Infiltrating ceramic skeletons with heat-resisting alloys has been considered as a means of producing a material that is sound and that has a microstructure which yields better impact properties than those obtained by conventional powder-metallurgy methods. The impact properties of one such material are given in reference 1 and are superior to those of a number of cold-pressed and sintered cermets of other compositions, also reported.

The data in reference 2 indicate that the most promising infiltrated titanium carbide cermets investigated were obtained with nickel-base alloys as the infiltrant. Of this group, cermets infiltrated with Hastalloy C or with Inconel had the best hot ductility and impact strength. Experience with cold-pressed and sintered titanium carbide compositions (ref. 3) implies a need for improved ductility in cermet gas-turbine blades and suggests investigation of blades of these two infilitrated cermet compositions.

In an exploratory study (ref. 4), titanium carbide infiltrated with Inconel was investigated for gas-turbine blades and on the basis of strength was found to be promising.

An investigation was conducted at the NACA Lewis laboratory to study titanium carbide infiltrated with Hastalloy C for gas-turbine-blade use. Stress-rupture tests were made at 1600° and 1800° F at stresses giving lives as high as about 1000 hours. Turbine blades of the cermet were evaluated to indicate the potential of the composition at centrifugal-stress conditions encountered in a low-blade-stress jet engine. Blades that survived considerable time at this stress condition were subjected to a higher centrifugal stress to indicate behavior in a high-blade-stress jet engine. The blade temperature used was approximately 1500° F.

MATERIALS

The cermet consisted of titanium carbide infiltrated with 50 percent by weight of Hastalloy C. The nominal composition of Hastalloy C (percent by weight) is

C	Cr	Ni	Co	Mo	W	Fe	V
0.09	16.5	54	1.2	17	4.5	5	0.3

Control blades of HS-21 (a cast cobalt-chromium-base alloy) were operated with the cermet blades to provide a basis of comparison. Blades of S-816 (a wrought cobalt-chromium-nickel-base alloy) were also used. These blades, however, could not be used as a basis of comparison because of impact damage.

Stress-Rupture Specimens

Stress-rupture specimens of the shape shown in figure 1(a) were produced by the Sintercast Corporation of America. When the specimens were received, they were surface inspected by use of a penetrant-oil method. There were indications of minor porosity which were not considered sufficiently serious to preclude testing.

Turbine Blades

Rectangular blocks of titanium carbide suitable for infiltration were supplied by the Sintercast Corporation and were machined to blade shape at the Lewis laboratory. The machined blocks were then infiltrated by the manufacturer and returned to the laboratory for final finishing by diamond grinding. After final grinding, the blades were checked for soundness by radiographic and penetrant-oil methods. The radiographs indicated that the blades were acceptable, and the surface inspection indicated only minor surface porosity in the airfoil. This porosity was not regarded as sufficiently serious to prohibit operation.

A cermet blade failure in the initial part of the program suggested that a more intensive inspection of the cermet blade surfaces would be advisable. This inspection was made visually using a microscope at magnifications as high as 200 diameters, and revealed minute surface cracks or tears, presumably due to grinding. Consequently, the airfoils of the remaining cermet blades were further finished by one of the two following methods:

Procedure	Blade number
Polishing with 4 to 5 micron diamond polish	4
Buffing with 120 grit alumina belt, "blinded" with beeswax	5 to 7

The polishing or buffing was carried out until all surface flaws visible by microscopic examination at X200 had been removed.

The cermet blade shape used in this investigation (fig. 1(b)) is the same as that used in previous studies of small-scale cermet turbine blades (refs. 3 and 4). The airfoils of the cermet blades and of the alloy control blades (fig. 2) are nominally the same. The roll and the neck of the cermet blade roots were larger than those of the alloy blades.

APPARATUS AND PROCEDURE

Stress Rupture

Commercial testing machines were used in obtaining the stress-rupture data. Details of the procedure are given in reference 5.

Blade Evaluation

The blade-evaluation unit consisted essentially of a turbojet combustion chamber and a small free-running turbine. This apparatus and turbine operating procedure are described in reference 3. Two cermet blades were run simultaneously in diametrically opposite positions in the turbine wheel. Because of accumulated turbine-wheel damage, three wheels were used. The first was replaced after failure of the third cermet blade; the second wheel was replaced after operation of cermet blades 6 and 7 had been initiated. Wheels 1 and 2 each had four new S-816 and six new HS-21 alloy control blades spaced approximately equally around the wheel. In each wheel, the S-816 blades were severely damaged, and, consequently, they could not be used for comparison purposes. The remaining blade spaces were filled with shorter blades (i.e., alloy blades with airfoils cut to about two-thirds of the original length) to reduce the possibility of their failing and damaging the cermet blades. All the test blades used in wheel 3 were transferred to it from wheel 2. Whenever a cermet blade failed, it was replaced by a new one, and the lives of all the cermet blades were compared with the lives of the original alloy control blade sample.

The turbine wheels were modified to take the larger base of the cermet blades by filling diametrically opposite wheel-rim segments with weld metal and machining these segments to the desired shape. An electroformed nickel-plated copper screen 0.0075 inch thick (fig. 3) was inserted between the root of each cermet blade and the turbine wheel to aid in redistributing any localized high stresses caused by imperfect mating of blade root and wheel dovetail.

The turbine was operated with an average nozzle-vane midspan temperature of 1550° F, which gave an estimated blade midspan temperature of 1500° F.

The wheels and blades were inspected at overhaul after blade failures. Cracks in the wheel rim were welded, and cracked nontest blades were replaced at these inspections.

The turbine was operated at two speeds. The lower speed, 22,850 rpm, was selected to produce an average centrifugal stress of 15,300 psi in the failure zone (the midspan) of the HS-21 alloy control blades. This value approximates the stress at the failure zone of blades of this alloy if they were operated at rated speed in the J47 engine. At this speed, the midspan stress was approximately 11,500 psi in the cermet blades. The differences in stress arise from the differences in the densities of the materials. The higher speed, 26,000 rpm, produced a midspan stress of about 19,800 psi in the HS-21 alloy blades, which approximated the stress at the failure zone of HS-21 alloy blades during operation in the J33 engine at rated speed. At this speed, the midspan stress was about 14,900 psi for the cermet blades. The cermet blades and the alloy control blades that survived more than 200 hours at 22,850 rpm were then subjected to the more severe centrifugal stress condition at 26,000 rpm.

RESULTS AND DISCUSSION

Metallographic Study

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The microstructure of the cermet is shown in figure 4. The metal phase appears to be continuous, and the carbide phase is rounded, that is, spheroidized. Spheroidization of the microstructure has been suggested (ref. 6) as a method of imparting ductility to an otherwise brittle cermet. While the effect of structure on ductility has not been definitely established, reference 1 reports that an infiltrated cermet had higher impact strength, than cold-pressed and sintered cermets of other compositions; the improvement is attributed to rounding of the carbide particles and to more even distribution of the carbides in the metal phase. The observed structure might also explain why blades of the present material appeared to be comparatively free of sensitivity to stress concentration, which will be discussed subsequently.

Stress Rupture

Results of the stress-rupture study are presented in figure 5. Failure of the cermet specimens generally occurred at the fillet between the conical portion and the cylindrical portion. This location of failure indicates that the observed stress-rupture values are lower than they might have been if failure had occurred toward the center of the specimen. The reason that failure occurred at the fillet is not clear. The occurrence of stress concentration effects in the tensile specimens is inconsistent with the blade results. Although two of the specimens showed severe oxidation (perhaps due to segregation) in small areas of the test bars, the remainder of the specimens were not appreciably attacked in the temperature range of 1600° to 1800° F.

Stress-rupture data at 1800° F for the test cermet are presented in figure 5(a); data for two other currently interesting materials are included to indicate the relative strength of this composition. Despite the higher metal content of the test cermet (50 percent by weight compared with 30 percent by weight for the other compositions), the strengths of the three materials were quite similar.

The 1600° F stress-rupture strengths for the infiltrated cermet and for the HS-21 control alloy are presented in figure 5(b). On the basis of these data alone, blades of the cermet would be expected to have longer lives than blades of this alloy.

Blade Evaluation

Description of failures. - A summary of engine operation is presented in table I. The simultaneous occurrence of a nearby wheel dovetail failure in the case of blade 1 and the appearance of blades 2 and 4 after failure indicate that these three failures were caused by impact. The failure in the base of blade 1 occurred completely across the neck just above the neck-roll juncture. The airfoil failure due to impact of blade 2 is shown in figure 6. This failure is similar in appearance to that of blade 4.

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Blades 6 (fig. 7) and 7 failed at about midspan along with the failure of several short metal blades. Previous experience with alloy blades indicates that the failure of the airfoil of either cermet blade would not be expected to set up sufficient vibration to cause the failure of metal blades. Hence, it appears likely that the alloy blades failed first and caused cermet blade failure by impact or excessive vibration. In the case of blade 7, the possibility that failure occurred by impact was strenghtened by the observation that the blade was chipped (fig. 8). In either blade, there is also the possibility of failure due to normal stresses.

Blade 3 also failed in the airfoil section. Study of a photomicrograph of the edge of the fracture of this blade (fig. 9) revealed an oxide layer, of which the initial portion was about the same thickness as the exterior surface oxide layer. This observation suggests that a surface flaw had been present and had caused failure of this blade. The surface-finishing procedures, mentioned previously, were used on blades 4 to 7 and were intended to eliminate such flaws.

The failure of cermet blade 5 in the base at the juncture of the neck and the roll (fig. 10) in a manner similar to the failures in blades of other cermet compositions (refs. 3 and 5) may have been due to stress concentration effects. The unusually short time to failure suggested that this blade might have also failed as a result of a structural flaw. Inspection of the failure revealed a possible zone of inhomogeneity.

Operating lives. - The operating lives of the cermet blades (table I) indicate that at a centrifugal stress of about 11,500 psi, long service lives can be obtained (blades 3, 4, 6, and 7). In all instances, cermet-blade failures can be attributed to defects in the material or to external causes, such as impact or severe vibration. Thus, there is the possibility that blades of this cermet can yield lives longer than those obtained in this study. The two cermet blades that were subjected to higher centrifugal stress failed a short time after the stress was increased; the behavior at the higher stress alone or the effect of change in stress is not known.

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At the conclusion of operation with wheel 1, three of the six HS-21 alloy control blades were found to be severely damaged by impact. A new set of six HS-21 alloy control blades was installed in wheel 2. Three of these blades failed as a result of impact occurring at varying times. Two of the three remaining blades failed by stress-rupture mechanisms after they had survived about $312\frac{1}{2}$ hours at the low-stress conditions and $2\frac{3}{4}$ hours at the high-stress condition. The final blade lasted the entire test without rupture. The inspection after the completion of this run revealed that the blade was cracked transversely at the midspan portion of the airfoil.

A comparison of the performance of the cermet blades with that of the control alloy blades shows that both types of blade were damaged by impact. Cermet blades 6 and 7 withstood repeated impact (fig. 3) without catastrophic failure. Although the airfoil mass of these blades was reduced by chips removed by impact, the total reduction in mass was not great, and the effect upon blade centrifugal stress was not believed appreciable. The cermet blades, however, tended to undergo catastrophic failure upon impact. The alloy control blades, on the other hand, generally appeared better able to resist impact (fig. 11); these blades were nicked and their edges were torn. This damage, however, was less extensive than that of the cermet blades.

Because so many of the cermet blades failed from external causes (i.e., flaws or impact), it is impossible to draw definite conclusions concerning the effects of airfoil finishing procedure. Surface buffing, however, seemed to improve blade life, since blade 3, which probably failed because of a surface flaw, failed at about 109 hours, whereas the buffed blades survived two and three times as long at the same conditions, without failure.

In a previous study of cermet blades in this engine (ref. 3), the principal cause of blade failure appeared to be stress concentrations in the root. In the present study, the blades had the same root form but were made of an infiltrated, instead of a cold-pressed and sintered, composition. Only two of seven of the infiltrated blades failed in the root; one of these blades probably failed from impact, and the other may have failed either because of stress concentration or because of a flaw in the material. This improvement in performance suggests that this material may have more nearly the ductility required to overcome the stress concentrations inherent in this blade design. Ductility data for this composition at elevated temperature are given in reference 2, in which 1800° F stress-rupture elongations as great as 20 percent are indicated.

SUMMARY OF RESULTS

An investigation of the blade-life properties of a cermet made by infiltrating titanium carbide with Hastalloy C gave the following results:

1. The stress-rupture properties of this cermet were superior to those of HS-21 alloy at 1600° F and were similar to those of presently interesting cermets at 1800° F.

2. Cermet blades survived as long as approximately $312\frac{1}{2}$ hours of operation at about 1500° F with an average midspan centrifugal stress of 11,500 psi. In all instances, cermet-blade failure could be attributed either to flaws in the material or to external causes, such as impact or excessive vibration. 3713

3. The high incidence of cermet and alloy blade failure due to external causes prevented a reliable comparison of operating lives.

4. Root failures such as those observed in an earlier cermet-blade study using similar blades of cold-pressed and sintered cermets of other compositions were less prevalent in this investigation. Blades of the present cermet thus seem to be less sensitive to notch effects.

5. Buffing the cermet blades appeared to be beneficial; however, because of the large number of damage failures encountered, this result was inconclusive.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, October 19, 1955

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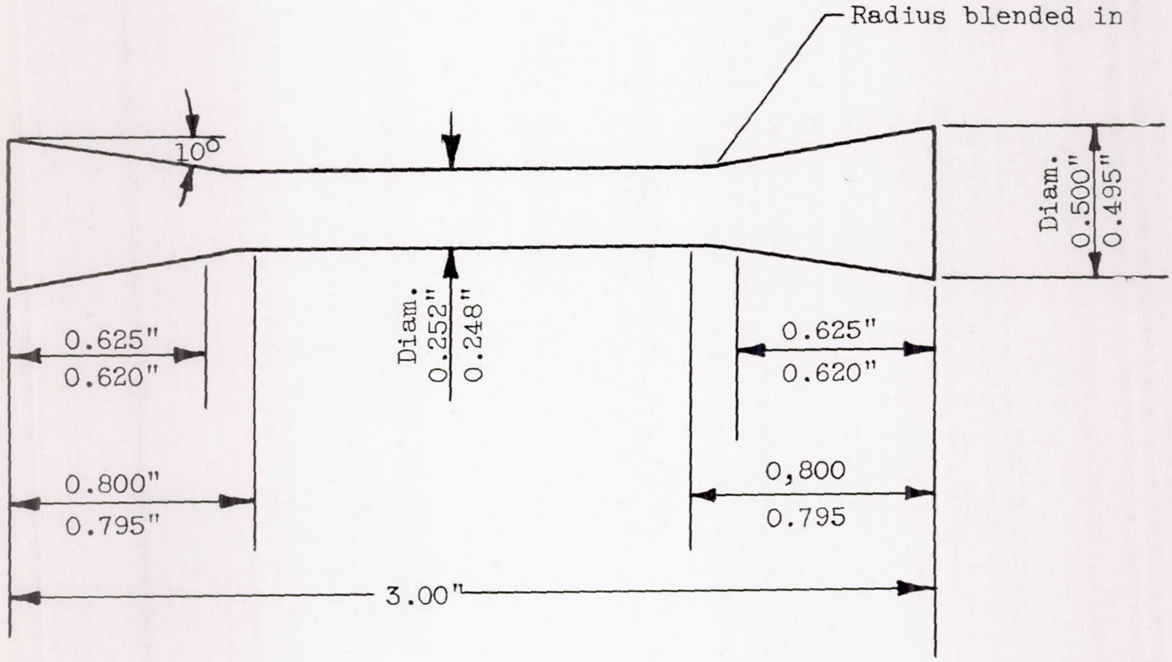
TABLE I. - SUMMARY OF CERMET BLADE LIVES AT 1500° F

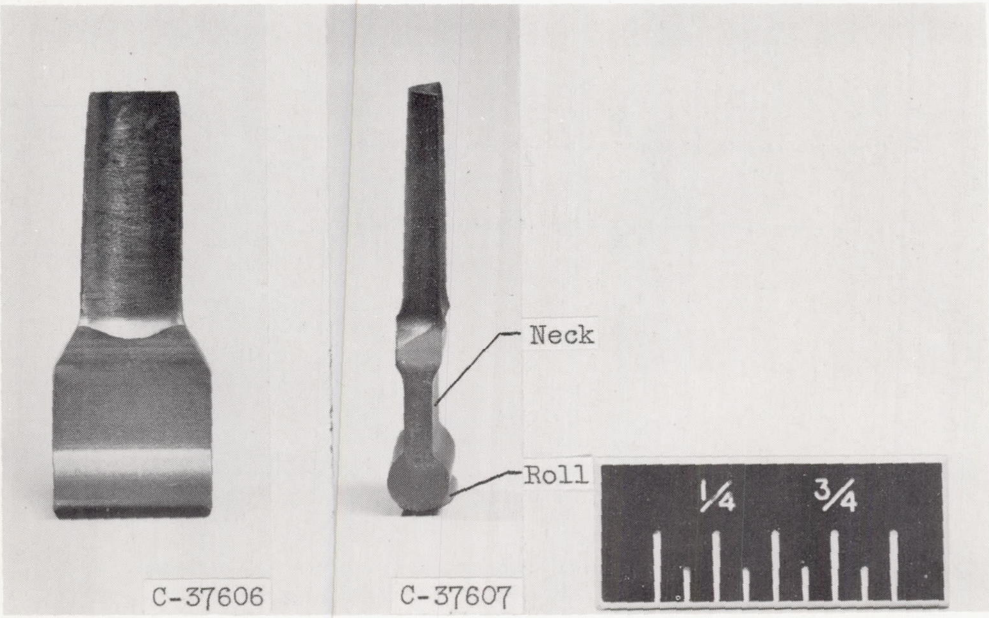
Blade	Wheel	Airfoil finish	Time at midspan stress of 11,500 psi (a)		Time at midspan stress of 14,900 psi (b)		Failure location and probable cause
			Hr	Min	Hr	Min	
1	1	Ground	34	59	-	--	In base above neck-roll juncture, due to impact with wheel dovetail.
2	1	Ground	74	21	-	--	In airfoil, due to impact with blade, or dovetail fragments, or both.
3	1	Ground	109	20	-	--	In airfoil approximately at midspan, due to surface flaw.
4	2	Diamond polish	96	30	-	--	In airfoil, due to impact with blade, or dovetail fragments, or both.
5	2	Buffed	0	55	-	--	In base at neck-roll juncture, due to abnormality in material or stress concentration.
6	2,3	Buffed	216	50	5	10	In airfoil at about mid-span, due to impact, vibration, or normal failure.[c]
7	2,3	Buffed	312	25	2	20	In airfoil at about mid-span, due to impact, vibration, or normal failure.[c]

[a]This stress corresponds to a wheel speed of 22,850 rpm.
[b]This stress corresponds to a wheel speed of 26,000 rpm.
[c]Failure due to normal stresses.



(a) Stress-rupture specimen.

Figure 1. - Cermet specimens.



(b) Blade.

Figure 1. - Concluded. Cermet specimens.

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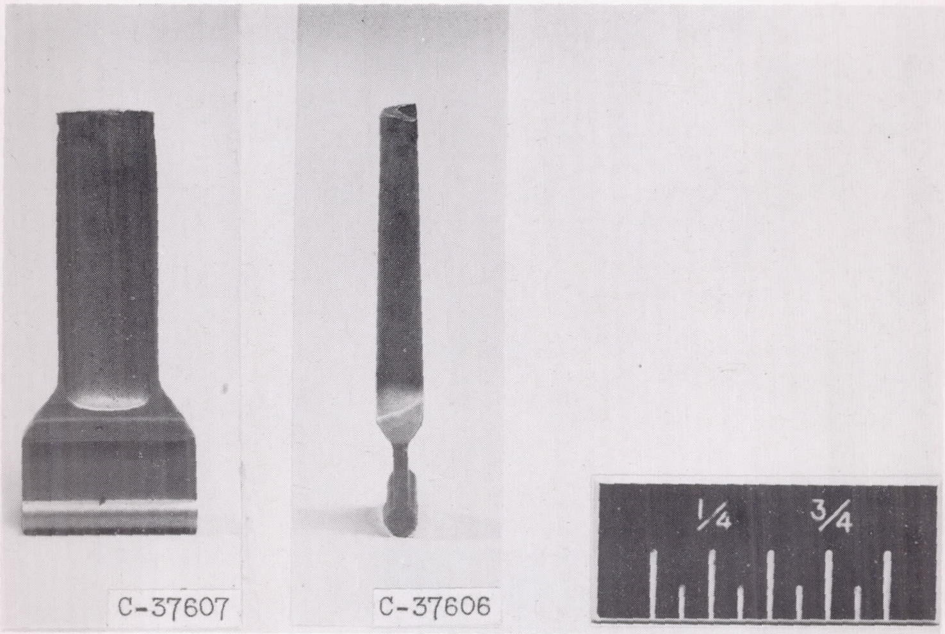

Figure 2. - Alloy control blade.

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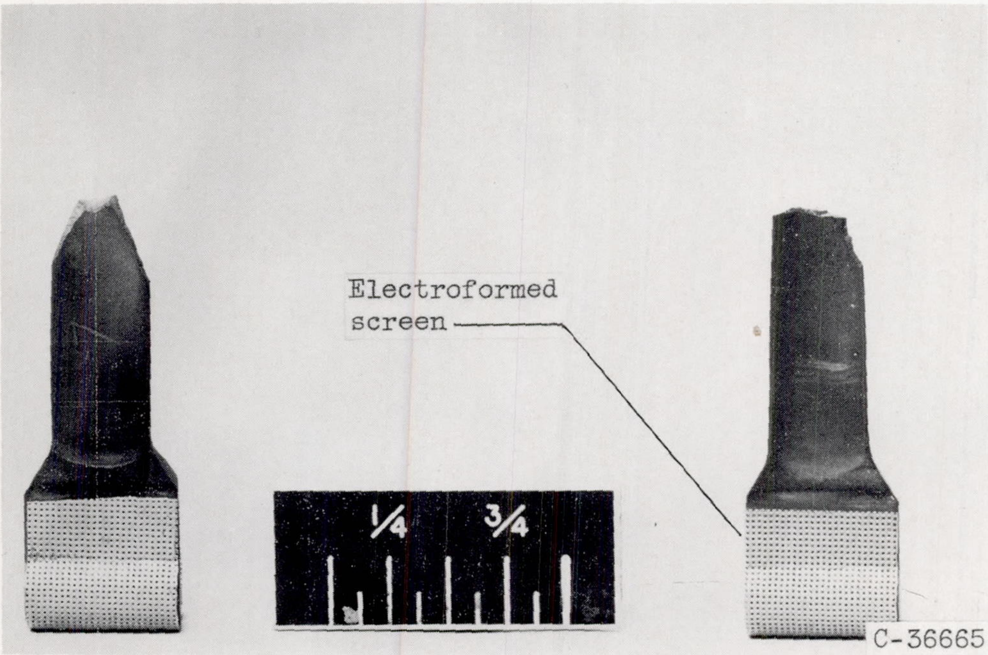

Figure 3. - Impact damage to cermet turbine blades 6 and 7.

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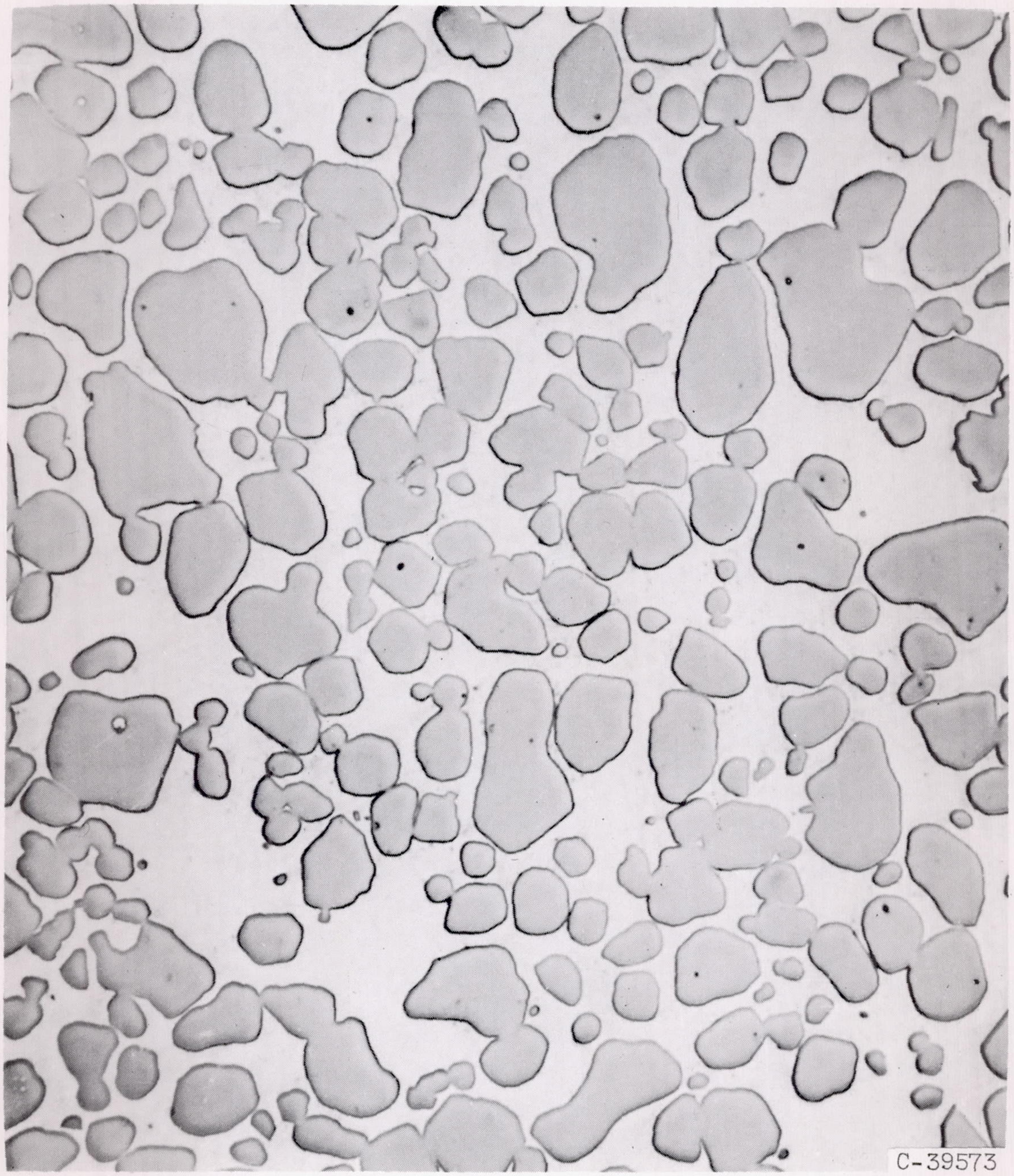
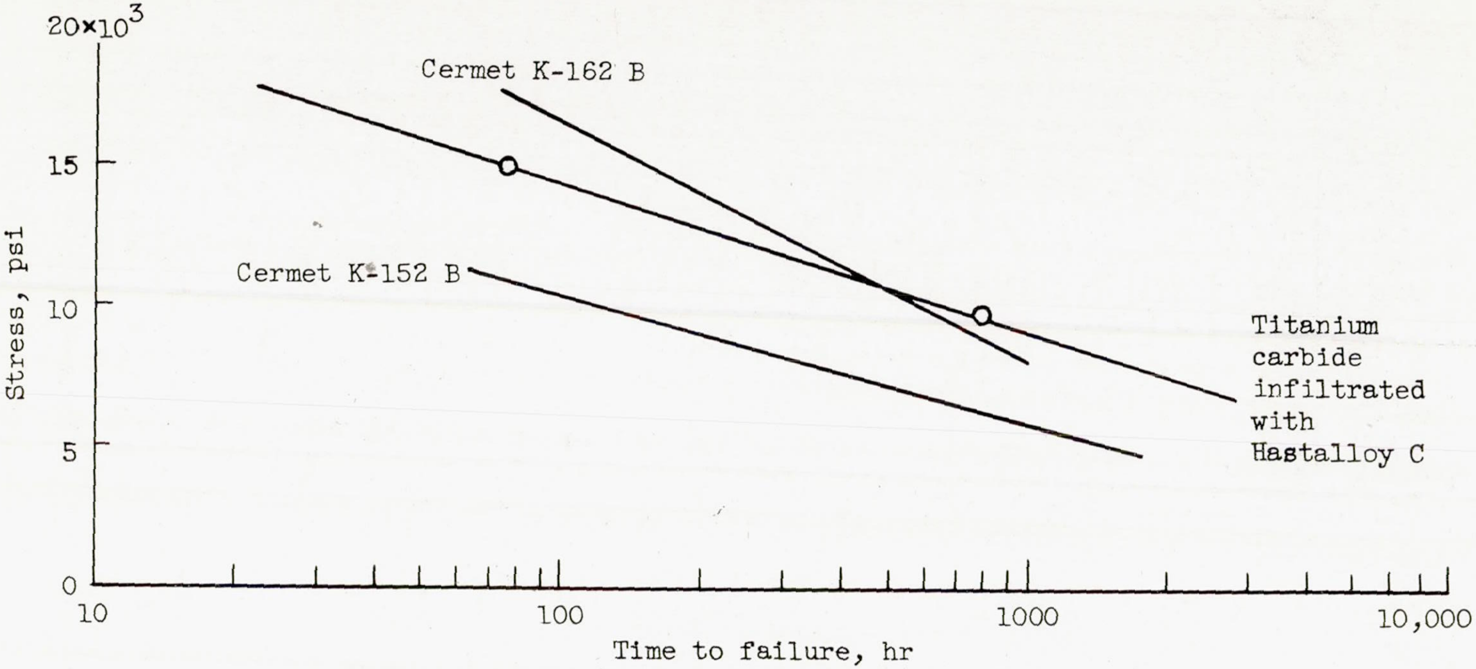
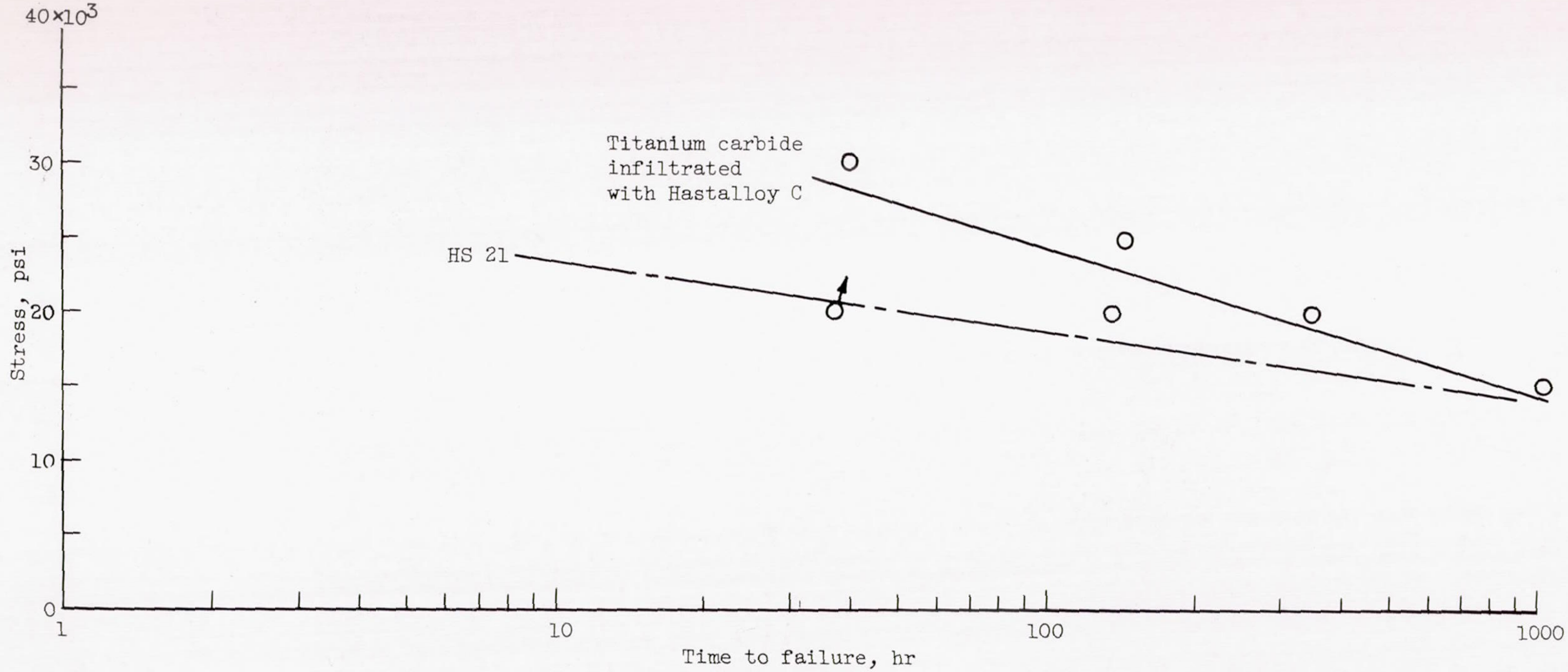


Figure 4. - Titanium carbide infiltrated with Hastalloy C. Unetched; X1000.



(a) 1800° F.

Figure 5. - Comparative stress-rupture strengths.



(b) 1600° F.

Figure 5. - Concluded. Comparative stress-rupture strengths.

Figure 6. - Cermet turbine blade 2 after failure caused by impact.

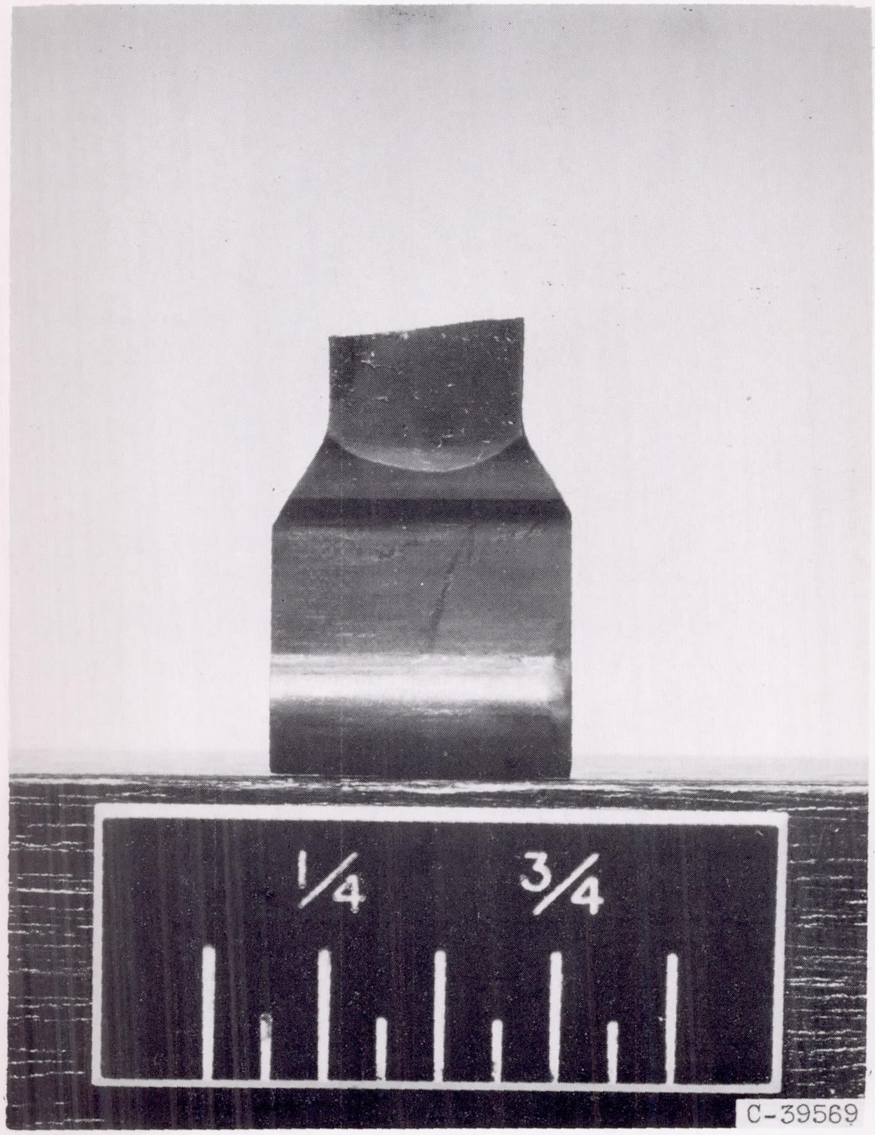


Figure 7. - Midspan failure of cermet turbine blade 6.

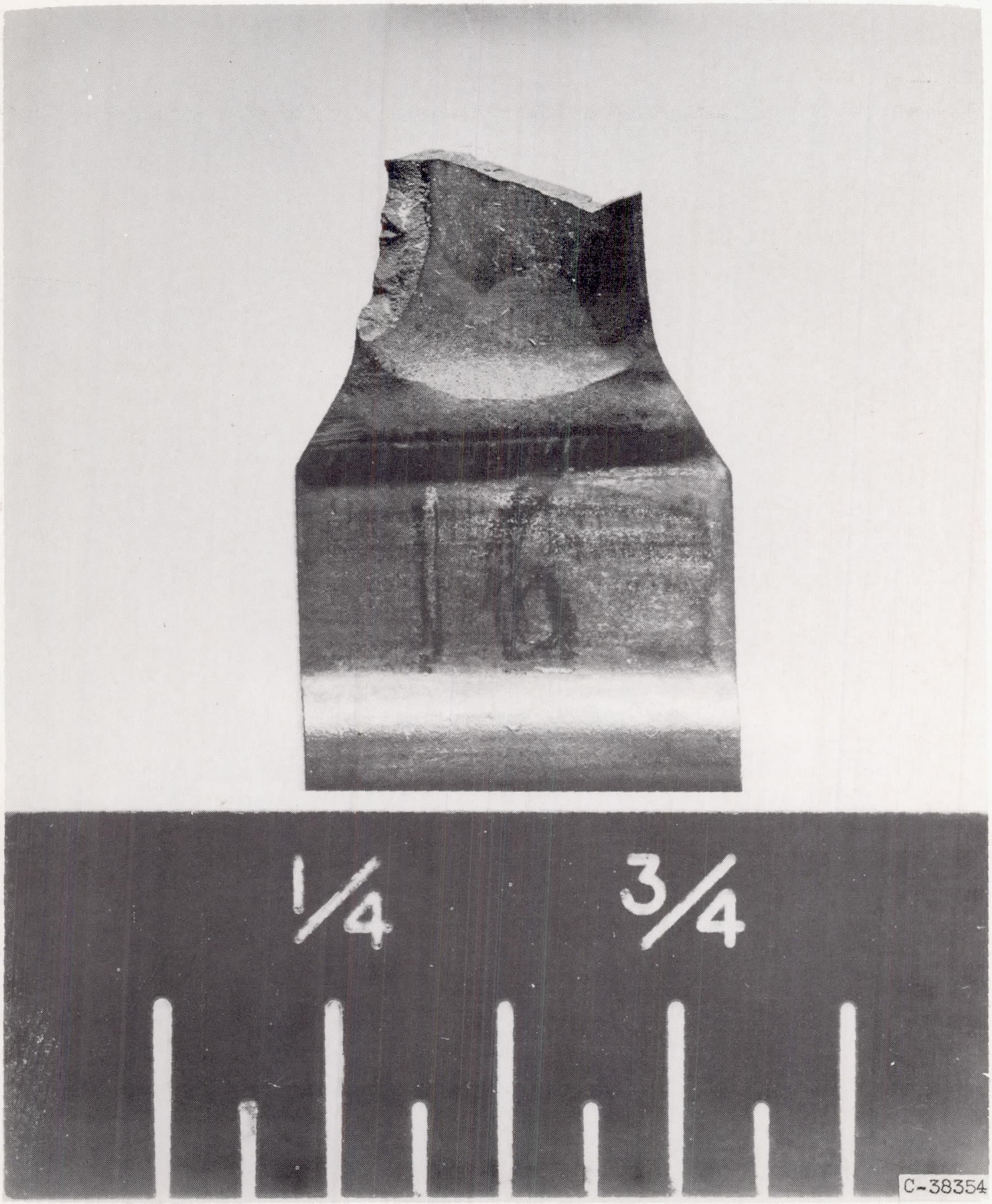


Figure 8. - Cermet blade 7, which may have failed by impact.

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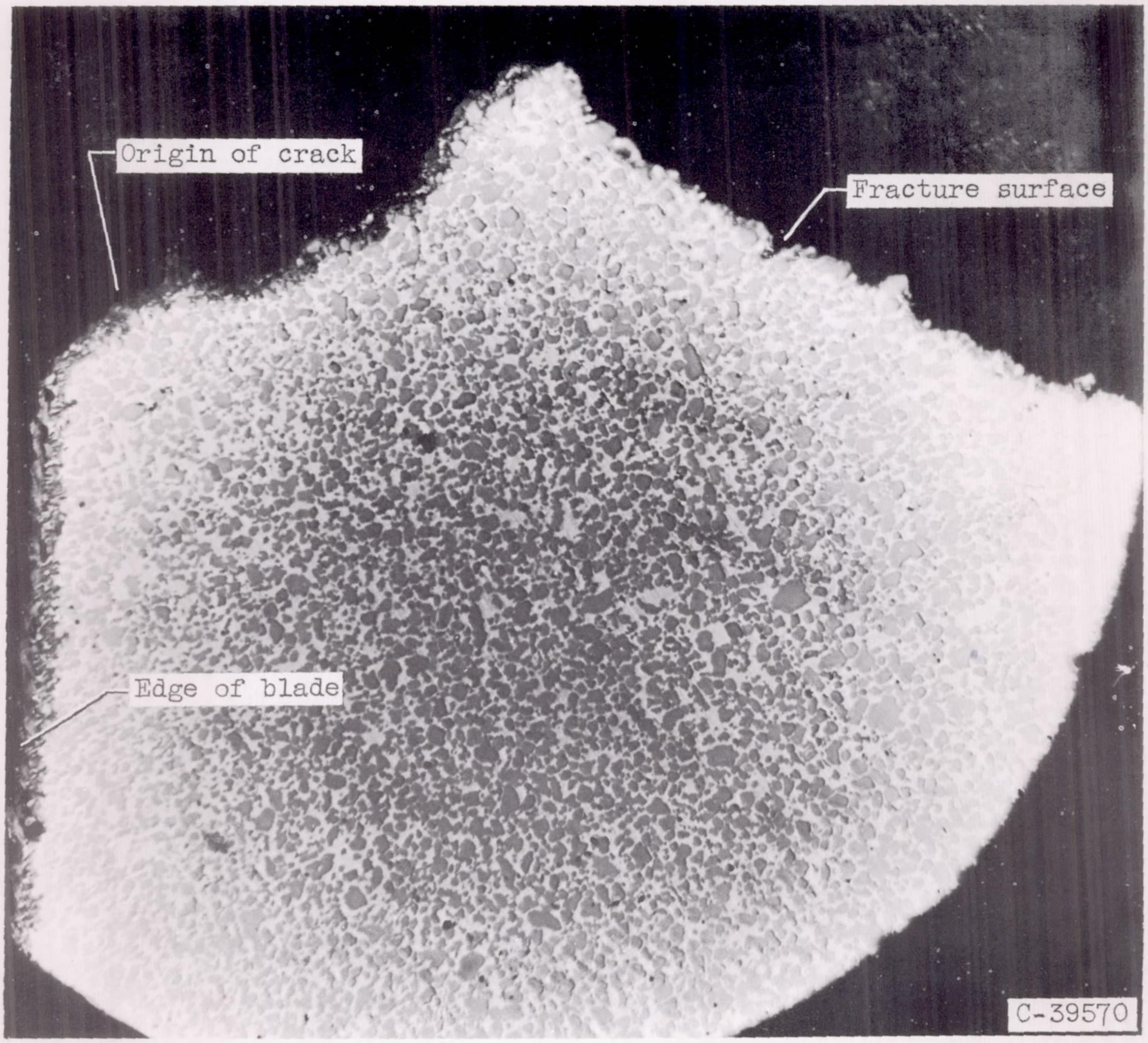

Figure 9. - Oxidation of surface crack of cermet blade 3. X150.

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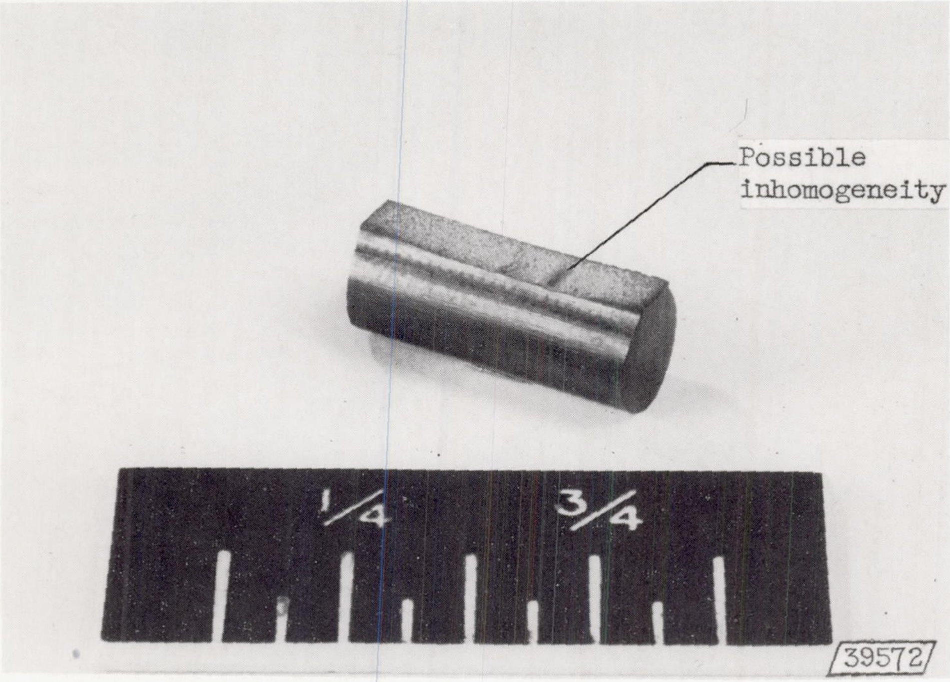

Figure 10. - Failure of cermet blade 5 at juncture of neck and roll.

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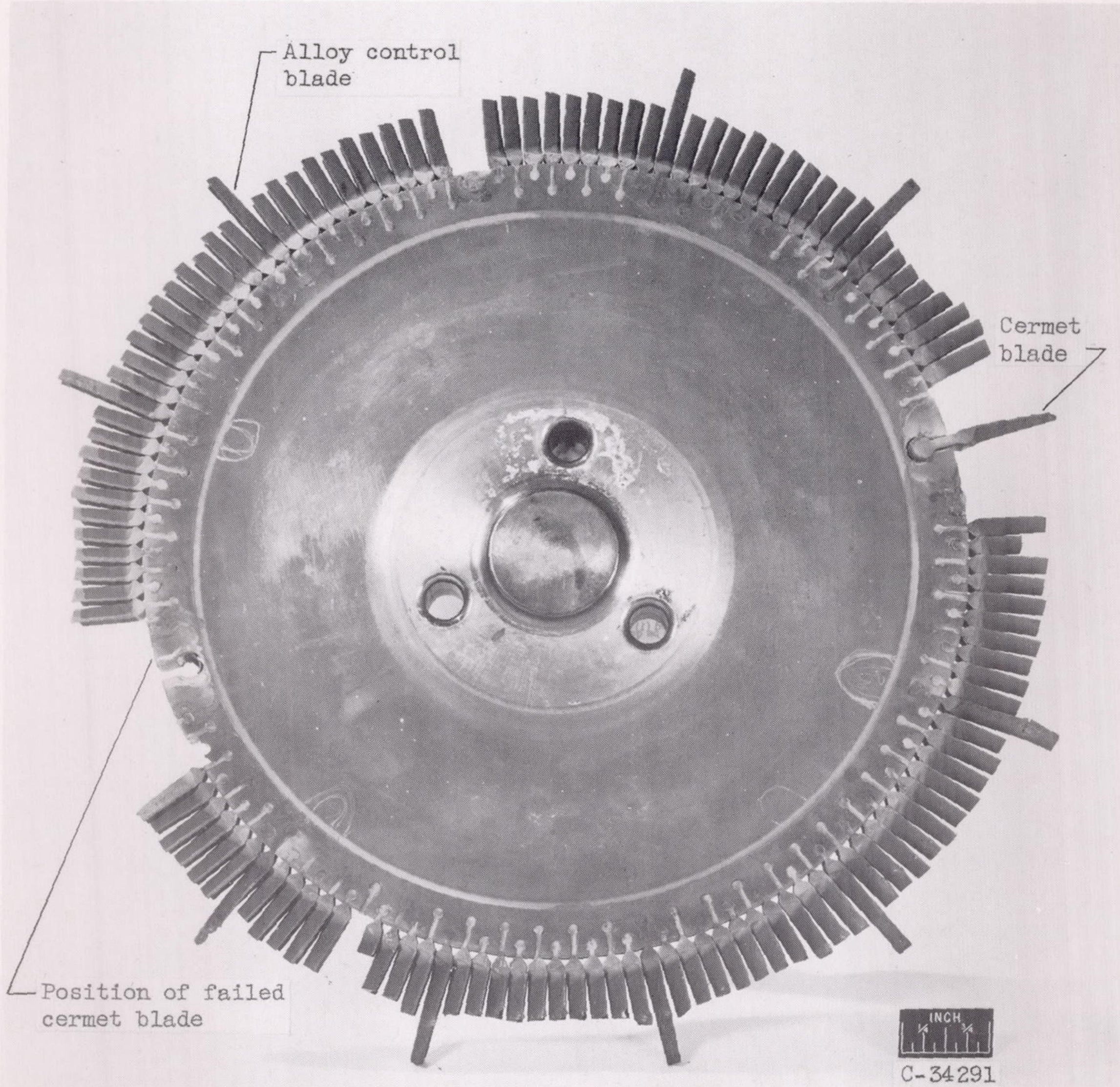

Figure 11. - Rear view of wheel 1 after failure of cermet blade 3.

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